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DISCUSSION

STOCHASTIC SEISMIC PERFORMANCE EVALUATION OF TUNED LIQUID COLUMN DAMPERS[1]

DISCUSSION BY LUIS ESTEVA AND SONIA E. RUIZ*

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Conventional mechanical tuned mass dampers (MTMD) are capable of producing substantial reductions in the dynamic response of long-period structures subjected to long duration, narrow band earthquake ground motion, particularly when the dominant period of the ground motion and the fundamental period of the structure are nearly equal. The efficiency of the dampers is highest for values of the tuning ratio (γ in the article) near 1.0. Their use under practical conditions is limited by some significant drawbacks:

(a) Significant reductions in the dynamic response of the main system (MS) are usually accompanied by very large deformations of the MTMD. This makes it difficult to design and build practical, inexpensive systems, capable of taking the required deformations.
(b) The reduction is very sensitive to the tuning ratio. Therefore, relatively small deviations of the actual properties of the MS and the MTMD with respect to their expected values assumed when designing may lead to very large differences in the reduced response ratio (response with MTMD/response without MTMD). Thus, when uncertainties about the mechanical properties of both systems are considered, the expected value of the reduced response ratio of a system designed for optimum response reduction conditions on the basis of nominal or expected values of those mechanical properties, may be significantly larger than that estimated on the basis of the assumed properties.
(c) For systems with natural vibration frequencies close to the dominant frequencies of the ground motion, the response reductions decrease with the degree of non-linearity of the response of the MS.

For instance, for a 20-storey shear building with a natural period of 2·03 s subjected to the EW component of the ground motion recorded at the SCT site (soft soil in Mexico City) during the Michoacan earthquake, of 19 September 1985, the use of a TMD with damping of 5 per cent of the critical, a tuning ratio equal to unity and a mass ratio of 0·03 reduces by 40 per cent the lateral displacement at the top of the building, assuming that its response is linear. This would require designing for a lateral force coefficient of 0·6, which would be prohibitively expensive. If the structure is designed for one fourth of the forces necessary to maintain linear behaviour, the displacement response reduction is only 22 per cent (Ruiz and Esteva, 1996). In other words, for high intensity earthquakes the response reductions do not suffice to prevent the occurrence of significant levels of non-linear behaviour, thus implying non-achievement of efficient performance conditions for MTMDs.

Tuned liquid column dampers (TLCD) provide a very ingenious and efficient way to cope with the problem of accomodating the large deformations of the damper that accompany the achievement of large reductions in the response of the MS. However, they do not seem (at least the article under discussion does not show it) to attenuate the other two limitations mentioned above. Therefore, as for MTMD, their practical application in earthquake engineering is probably restricted to the reduction of expected damage in structural and non-structural elements during moderate-intensity earthquakes.

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In p. 1270, the authors state that, for a structure with natural frequency of 2·2 rad/s, and a TLCD such that the tuning ratio is 1·0 and the mass ratio is 0·04, subjected to a stochastic model of the ground acceleration, with intensity and frequency content properties similar to those of the S60E component of the SCT record of the 1985 Mexico City earthquake, "… a very small response reduction (about 5 per cent) can be attributed to structural frequency change resulting from the added mass of the damper". For a load factor such that the TLCD remains linear, this statement seems to contradict the conclusions that may be readily derived from Fig. 5 of the article. For a two degrees of freedom model of a combined MS-MTMD system (assumed to represent an MS-TLCD system for small values of LF), an MS natural frequency of 2·2 rad/s, a tuning ratio of 1·0, and a mass ratio of 0·04, the first and second natural frequencies are, respectively, 1·991 and 2·431 rad/s, and the corresponding modal shapes are (1, 5·52) and (1, $-4{\cdot}53$). From Fig. 5 of the article, the ordinates of the displacement response spectrum are 220 cm for the MS, 120 and 175 cm for the first and second frequencies of the combined system (respectively, 0·55 and 0·80 times the spectral ordinate for the assumed period of the MS); the corresponding participation factors are 0·55 and 0·45. With this information, Newmark and Rosenbuleth's (1974) double quadratic sum for modal response superposition leads to a relative displacement of 109·7 cm for the mass of the MS, which is approximately 50 per cent of 220 cm.

According to these figures, a reduction of about $1\text{–}0{\cdot}5\,(0{\cdot}55 + 0{\cdot}80) = 0{\cdot}325$ can be attributed to the mean value of the reductions in the spectral ordinates for the natural frequencies of the combined MS-TMD system relative to the ordinate for the frequency of the MS system alone; it is an immediate consequence of the narrowness of the peak of the response spectrum. The rest of the reduction is due to the uncoupling of the responses of the two modes of the combined system. According to Newmark and Rosenblueth's superposition rule, the influence of this uncoupling on the decrease of the maximum response grows with the effective duration of the ground motion.

The sensitivity of the expected value of the response reduction to the uncertainty in the actual value of the tuning ratio can be estimated, for instance, by assuming two tuning ratios, $\gamma_1 = 0{\cdot}95$ and $\gamma_2 = 1{\cdot}05$, each with probability 0·5 of being true, instead of a deterministic value of 1·0. We would obtain reduced response ratios of 0·59 and 0·53, respectively, for an expected value of 0·56, 12 per cent larger than the theoretical value of 0·50.

Finally, because the damping value assumed for the MS is very small as compared to those typically used to estimate the responses of civil engineering structures to moderate earthquakes, the reduction values shown in the article may be too optimistic even for applications to reduce damage under this type of events.

In spite of the foregoing comments, the authors of this discussion wish to endorse the conclusion of considering TLCDs as promising passive control devices (not only for periods longer than about 2·5 s) for moderate earthquakes. Future studies should include (a) cost–benefit evaluations of their use in the reduction of structural and non-structural damage for earthquakes of different intensities, and (b) optimum seismic design criteria for both damage and failure limit states.

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